4.4. Pest Management

Insects, disease, and weeds cause significant yield and quality losses to U.S. crops, and farmers currently rely on pesticides to combat this damage. However, many scientists now recommend greater use of biological and cultural pest management methods, and biological products, such as Bacillus thuringiensis, have recently captured a small share of the pest control market. Government programs to encourage the development and use of biological and cultural methods include areawide pest management, integrated pest management (IPM), national organic standards development, and regulatory streamlining for biologicals.

Contents

For nearly four decades, the majority of U.S. farmers have relied on synthetic pesticides as their primary method for managing most crop pests in most commodities. Farmers adopted synthetic pesticides quickly after their commercial introduction in the 1940's because they were inexpensive, effective, and easy to apply (MacIntyre, 1987). Biological and cultural control methods such as Bt applications and trap cropping, which use living organisms and strategic cropping to combat pest damage, are not as widely used (see glossary for definitions of terms and methods).

During the early 1990's, USDA's Economic Research Service (ERS), using a producer probability survey representing over 60 percent of U.S. crop production, began compiling a baseline on the uses of various chemical, cultural, and biological practices to control pests. According to these data, pesticides are used on the majority of crop acreage of most major commodities. Most growers also used scouting, economic thresholds, and other pesticide-efficiency techniques, but less than half reported the use of cultural and biological techniques. (For information on pesticide quantitities and active ingredients, see chapter 3.2, *Pesticides*.)

The National Research Council recently concluded that pest resistance and other problems created by pesticide use had created an "urgent need for an alternative approach to pest management that can complement and partially replace current chemically based pest-management practices" (National Academy of Sciences, 1985). Various government programs and activities are being initiated to encourage increased use of integrated pest management (IPM) and other strategies to reduce pesticide use and risks, and to promote research and implementation of biological and cultural controls (Jacobsen, 1996; Browner, 1993).

Why Manage Pests?

Approximately 600 species of insects, 1,800 plant species, and numerous species of fungi and nematodes are considered serious pests in agriculture (Klassen and Schwartz, 1991). If these pests were not managed, crop yields and quality would fall substantially, likely increasing production costs and food and fiber prices. In addition, producers with greater pest problems would become less competitive.

Cultural and biological techniques were the primary methods used to manage pests in agriculture for thousands of years. U.S. farmers began shifting to chemical methods upon the successful use of a natural arsenic compound to control Colorado potato beetles in 1867 (National Academy of Sciences, 1995) and the inception of USDA's chemical research program in 1881 (Klassen and Schwartz, 1991).

The increases in crop yields throughout this century have been partly credited to pesticide technology; the majority of U.S. crop acreage is now treated with pesticides. The benefits of pesticides, the value of production that would be lost if alternatives were less effective, and the additional pest management costs if alternatives were more expensive have been shown in numerous studies (Osteen, 1987). The costs of pesticide use to human health and the environment have been much more difficult to quantify. A preliminary Cornell study estimates that the costs from human pesticide poisonings, reduction of fish and wildlife populations, livestock losses, honey bee losses, destruction of beneficial insects, pesticide resistance, and other pesticide effects are $8 billion annually in the U.S. (Pimentel and others, 1992). An alternative method that is more expensive or less effective than pesticides might be economically justified when weighed against the indirect costs of pesticides (see box, "Why Reduce Reliance on Pesticides?").

Pest Management Systems and Practices

USDA cropping practices and chemical use surveys between 1990 and 1995 provide information about chemical, cultural, and biological pest management systems for five major field crops (corn, soybeans, wheat, cotton, and potatoes) and selected fruits and vegetables. About 60 percent of U.S. cropland planted to crops was represented in these annual surveys.

Pesticide-Based Management

Pesticides are applied annually to the majority of U.S. crop acreage. One or more pesticides are used to control weeds and other pests of major field crops, corn, soybeans, wheat, cotton, and potatoes (table 4.4.1), as well as most fruit and vegetable crops (table 4.4.2).

Corn. The largest crop in the United States is corn, and it exceeds any other crop in the number of acres treated with pesticides (table 4.4.1). At least some herbicide was applied to 98 percent of the corn area in the 10 surveyed States in 1995, up from 95 percent in 1990. While the total amount of herbicide applied per acre fell slightly, the number of herbicide treatments and number of different ingredients applied per acre increased. The use of more frequent treatments and additional ingredients reflects an increase in the number of treatments later in the growing season and the grower's need for more broad-spectrum weed control. Treatments applied later in the growing season are less likely to run off or leach and are more likely to be post-emergence herbicides, which are often less persistent in the environment. The amount of herbicide applied per acre has fallen with the increased use of low-rate sulfonylurea herbicides and with reduced-rate applications of atrazine and other older herbicides.

Less than one-fourth of the corn acreage received insecticides in 1995, and corn rootworm was the most frequently treated insect. Insecticide applied to the soil before or during planting kills hatching rootworm larvae and is a common control method, especially when corn is planted every year. Corn acreage treated with insecticides in 1995 was down 6 percentage points from 1990. This decline may be due to closer monitoring of insect and mite populations in the previous crop to decide if preventive treatments are needed.

Soybeans. Herbicides account for virtually all the pesticides used on the soybean crop. In the late 1980's, sulfonylurea and imidazolinone herbicides, which could be applied at less than an ounce per acre, began to replace older products commonly applied at 1 to 2 pounds per acre. They are now among the most commonly used soybean herbicides and have caused total herbicide use to drop. However, the number of acres treated and number of treatments per acre have increased, partly due to the growth in no-till soybean systems, which often replace tillage prior to planting with a preplant "burndown" herbicide to kill existing vegetation. The area treated with herbicides after planting increased from 52 percent to 74 percent from 1990 to 1995, while treatments before planting dropped only a few percentage points.

Wheat. Wheat is one of the largest field crops in the United States, in terms of acreage, and is the least pesticide-intensive. Wheat accounted for 29 percent of the surveyed acreage in 1994, but received only 4 percent of the pesticides. Herbicides were applied on about half of the winter wheat, the largest wheat crop, in 1995, up from only 34 percent in 1990. Winter wheat grows through the fall and winter, and many weeds germinating in the spring cannot compete with the established wheat. In contrast, spring wheat seedlings compete directly with weed seedlings in the spring, and nearly all of these crops receive herbicide treatments.

Why Reduce Reliance on Pesticides?

Concern about the side effects of synthetic pesticides began emerging in scientific and agricultural communities in the late 1940's, after problems with insect resistance to DDT. The public became concerned about the unintentional effects of pesticide use after Rachel Carson's book on bioaccumulation and other potential hazards was published in the 1960's. Many unintentional effects of pesticide exposure on nontarget species have been reported since then, including acute pesticide poisonings of humans (especially during occupational exposure) and damage to fish and wildlife, including species that are beneficial in agricultural ecosystems. Since the 1960's, some pesticides have been banned, others restricted in use, and others' formulations changed to lessen undesirable effects.

Human Health Impacts. The American Association of Poison Control Centers estimates that approximately 67,000 nonfatal acute pesticide poisonings occur annually in the United States (Litovitz and others, 1990). However, the extent of chronic health illness resulting from pesticide exposure is much less documented. Epidemiological studies of cancer suggest that farmers in many countries, including the United States, have higher rates than the general population for Hodgkin's disease, leukemia, multiple myeloma, non-Hodgkin's lymphoma, and cancers of the lip, stomach, prostate, skin, brain, and connective tissue (Alavanja and others, 1996). Emerging case reports and experimental studies suggest that noncancer illnesses of the nervous, renal, respiratory, reproductive, and endocrine systems may be influenced by pesticide exposure. Case studies, for example, indicate that pesticide exposure is a risk factor for several neurodegenerative diseases, including Parkinson's disease and amyotrophic lateral sclerosis, also known as Lou Gehrig's disease (Alavanja and others, 1993). A comprehensive Federal research project on the impacts of occupational pesticide exposure on rates of cancer, neurodegenerative disease, and other illnesses was begun about 4 years ago in North Carolina and Iowa; about 49,000 farmers who apply pesticides and 20,000 of their spouses, along with 7,000 commercial pesticide applicators, are expected to participate in the study (Alavanja and others, 1996).

Direct exposure to pesticides by those who handle and work around these materials is believed to pose the greatest risk of human harm, but indirect exposure through trace residues in food and water is also a source of concern (EPA, 1987). The effects of these pesticide residues on infants and children and other vulnerable groups have recently been addressed with a new legislative mandate in the Food Quality Protection Act of 1996 (see box, "Pesticide Tolerance and Dietary Risks" in chapter 3.2, *Pesticides*).

Environmental Quality. Documented environmental impacts of pesticides include: poisonings of commercial honeybees and wild pollinators of fruits and vegetables; destruction of natural enemies of pests in natural and agricultural ecosystems; ground- and surface-water contamination by pesticide residues with destruction of fish and other aquatic organisms, birds, mammals, invertebrates, and microorganisms; as well as population shifts among plants and animals within ecosystems toward more tolerant species.

Most insecticides used in agriculture are toxic to honeybees and wild bees, and costs related to pesticide damages include honeybee colony losses, honey and wax losses, loss of potential honey production, honeybee rental fees to substitute for pollination previously performed by wild pollinators, and crop failure because of lack of pollination (Pimentel and others, 1992). Approximately one-third of annual agricultural production in the United States is derived from insect-pollinated plants (Buchman and Nabhan, 1996), and flowering plants in natural ecosystems may not thrive because of fewer pollinators.

The destruction of the natural enemies of crop pests has led to outbreak levels of primary and secondary crop pests for some commodities, and pest management costs have increased when additional pesticide applications have been needed for these larger or additional pest populations. Measurable costs related to pesticide residues in surface- and groundwater include residue monitoring and contamination cleanup costs and costs of damage to fish in commercial fisheries. Birdwatching, fishing, hunting and other recreational activities have been affected by aquatic and terrestrial wildlife losses due to pesticide poisonings. An emerging issue is the environmental impacts of invertebrate and microorganism destruction because of the essential role they play in healthy ecosystems.

Pesticide Resistance. After repeated exposure to pesticides, insect, weed, and other pest populations in agricultural cropping systems may develop resistance to pesticides through a variety of mechanisms. The newer safety requirements for pesticide registration along with the increasing pace of pest resistance has raised doubts about the ability of chemical companies to keep up with the need for replacement pesticides. In the United States, over 183 insect and arachnid pests are resistant to 1 or more insecticides, and 18 weed species are resistant to herbicides (U.S. Congress, 1995). Cross-resistance to multiple families of pesticides, along with the need for higher doses and new pesticide formulations, is a growing concern among entomologists, weed ecologists, and other pest management specialists.

Emerging issues include the impact of endocrine-system disrupting pesticides on human health and wildlife, including potential reproductive effects and effects on child growth and development (EPA, 1997), and the impacts of exposure to pesticides, particularly the potential for synergistic impacts (Arnold and others, 1996).

Table 4.4.1—Pest management practices on major field crops in major producing States, 1990-95

Crop	Units	1990	1991	1992	1993	1994	1995
Corn (10 States):[1]							
Planted area	1,000 ac.	58,800	60,350	62,850	57,350	62,500	55,850
Area receiving herbicides	Percent	95	96	97	98	98	98
Before or at plant only	Percent	39	38	33	35	29	30
After plant only	Percent	29	34	36	37	38	38
Both	Percent	26	23	27	26	32	29
Avg. number of treatments/acre	Number	1.4	1.4	1.4	1.4	1.5	1.5
Avg. number of ingredients/acre	Number	2.2	2.1	2.3	2.3	2.5	2.4
Avg. amount applied	Lbs./ac.	3.24	2.97	2.98	2.94	2.79	2.76
Amount banded	Percent	7	7	9	8	8	6
Area receiving insecticides	Percent	32	30	29	28	27	26
Before or at plant only	Percent	26	23	23	22	19	18
After plant only	Percent	4	6	5	5	7	7
Both	Percent	2	2	1	1	1	1
Avg. number of treatments/acre	Number	1.1	1.1	1.1	1.1	1.1	1.1
Avg. number of ingredients/acre	Number	1.1	1.1	1.1	1.0	1.1	1.1
Avg. amount applied	Lbs./ac.	1.18	1.04	0.95	0.90	0.83	0.75
Area scouted for pests	Percent	na	na	na	65	77	na
Operator or family member	Percent	na	na	na	na	64	na
Chemical dealer	Percent	na	na	na	na	5	na
Commercial service	Percent	na	na	na	na	62	na
Other	Percent	na	na	na	na		na
Area under crop rotation	Percent	76	75	77	75	74	80
Area with cultivations for weed control	Percent	70	68	72	53	63	66
Soybeans (8 States):[1]							
Planted area	1,000 ac.	39,500	42,050	41,350	42,500	43,750	45,150
Area receiving herbicides	Percent	96	97	98	98	98	98
Before or at plant only	Percent	44	39	36	28	28	23
After plant only	Percent	20	26	28	30	29	32
Both	Percent	32	32	34	35	42	42
Avg. number of treatments/acre	Number	1.5	1.5	1.6	1.6	1.7	1.7
Avg. number of ingredients/acre	Number	2.3	2.3	2.4	2.5	2.7	2.7
Avg. amount applied	Lbs./ac.	1.39	1.27	1.14	1.11	1.14	1.09
Amount banded	Percent	6	5	5	5	4	4
Area with scouting for pests	Percent	na	na	na	70	76	na
Operator or family member	Percent	na	na	na	na	68	na
Chemical dealer	Percent	na	na	na	na	5	na
Commercial service	Percent	na	na	na	na	2	na
Other	Percent	na	na	na	na	1	na
Area under crop rotation	Percent	na	na	na	na	93	90
Area with crop cultivations for weed control	Percent	67	61	54	38	44	41
Winter wheat (11 States):[1]							
Planted area	1,000 ac.	38,900	31,000	33,990	35,500	32,930	32,670
Area receiving herbicides	Percent	34	26	31	40	46	54
Before or at plant only	Percent	3	3	1.5	3	4	4
After plant only	Percent	30	23	29	36	40	48
Both	Percent	1	1	0.5	1	1	2
Avg. number of treatments/acre	Number	1.1	1.1	1.1	1.1	1.1	1.1
Avg. number of ingredients/acre	Number	1.5	1.5	1.6	1.8	1.8	1.8
Avg. amount applied	Lbs./ac.	0.28	0.27	0.28	0.30	0.33	.25
Area with scouting for pests	Percent	na	na	na	na	na	80
Area under crop rotation	Percent	na	na	na	na	61	57
Spring wheat (4 States):[1]							
Planted area	1,000 ac.	15,800	13,500	17,350	16,950	17,250	15,750
Area receiving herbicide	Percent	91	92	88	96	95	95
Before plant only	Percent	1	3	6	4	4	2
After plant only	Percent	82	83	77	83	79	86
Both	Percent	8	7	5	9	11	7
Avg. number of treatments/acre	Number	1.2	1.2	1.2	1.2	1.2	1.2
Avg. number of ingredients/acre	Number	1.8	2.0	2.1	2.2	2.3	2.4

Continued--

Table 4.4.1—Pest management practices on major field crops in major producing States, 1990-95 (cont.)

Crop	Units	1990	1991	1992	1993	1994	1995
Spring wheat (cont.)							
Avg. amount applied	Lbs./ac.	0.52	0.47	0.49	0.49	0.52	0.54
Area with scouting for pests	Percent	na	na	na	na	na	82
Area under crop rotation	Percent	na	na	na	na	100	84
Cotton (6 States):[1]							
Planted area	1,000 ac.	9,730	10,860	10,200	10,360	10,023	11,650
Area receiving herbicides	Percent	95	92	91	92	94	98
Before or at plant only	percent	58	52	49	45	41	46
After plant only	Percent	6	5	9	10	6	7
Both	Percent	31	35	33	38	46	45
Avg. number of treatments/acre	Number	2.1	2.3	2.5	2.5	2.6	2.7
Avg. number of ingredients/acre	Number	2.3	2.5	2.7	2.7	2.7	2.8
Avg. amount applied	Lbs./ac.	1.79	2.01	2.11	2.01	2.23	2.03
Amount banded	Percent	33	35	33	31	27	28
Area receiving insecticides	Percent	na	66	65	65	71	76
Avg. number of treatments/acre	Number	na	3.1	4.5	4.9	5.7	6.2
Avg. number of ingredients/acre	Number	na	2.3	3.2	3.4	3.5	3.8
Avg. amount applied	Lbs./ac.	na	1.13	1.83	2.06	2.48	2.36
Area receiving other pesticides	Percent	na	56	47	64	67	57
Avg. number of treatments/acre	Number	na	1.8	1.6	1.6	1.7	2.1
Avg. number of ingredients/acre	Number	na	2.0	2.0	1.9	2.0	2.1
Avg. amount applied	Lbs./ac.	na	1.63	2.34	1.79	1.72	2.40
Area with scouting for pests	Percent	na	na	na	na	88	na
Operator or family member	Percent	na	na	na	na	30	na
Chemical dealer	Percent	na	na	na	na	10	na
Commercial service	Percent	na	na	na	na	40	na
Other	Percent	na	na	na	na	8	na
Area under crop rotation	Percent	na	na	na	na	31	32
Area with cultivations for weed control	Percent	97	94	92	96	98	98
Area with pheromones used to monitor pests	Percent	na	na	na	na	19	25
Area with pheromomes used to control pests	Percent	na	na	na	na	9	na
Area treated with purchased beneficial insects	Percent	na	na	na	na	2	1
Fall potatoes (11 States):[1]							
Planted area	1,000 ac.	1,087	1,123	1,064	1,114	1,140	1,147
Area receiving herbicides	Percent	81	81	82	82	84	86
Before or at plant only	Percent	16	13	14	14	16	10
After plant only	Percent	60	61	63	62	58	72
Both	Percent	6	7	5	7	10	5
Avg. number of treatments/acre	Number	1.3	1.4	1.3	1.3	1.4	1.4
Avg. number of ingredients/acre	Number	1.6	1.7	1.7	1.7	1.8	1.9
Avg. amount applied	Lbs./ac.	2.15	2.29	1.94	2.06	2.42	2.40
Amount banded	Percent	3	4	2	1	2	1
Area receiving insecticides	Percent	89	92	90	88	88	88
Before or at plant only	Percent	18	13	14	14	16	16
After plant only	Percent	52	58	60	59	59	53
Both	Percent	19	21	17	16	13	19
Avg. number of treatments/acre	Number	2.0	2.2	2.3	2.2	2.7	2.5
Avg. number of ingredients/acre	Number	1.8	1.9	2.0	2.0	2.1	1.9
Avg. amount applied	Lbs./ac.	3.15	2.81	2.89	2.90	3.49	2.55
Area receiving fungicides	Percent	69	69	72	76	80	85
Avg. number of treatments/acre	Number	2.7	2.7	3.1	3.4	4.2	6.1
Avg. number of ingredients/acre	Number	1.4	1.5	1.9	2.1	3.2	2.7
Avg. amount applied	Lbs./ac.	3.17	3.42	3.93	4.22	5.61	6.75
Area receiving other pesticides	Percent	34.6	44.9	43.1	52.9	59.9	57.1
Avg. number of treatments/acre	Number	1.3	1.3	1.4	1.3	1.4	1.6
Avg. number of ingredients/acre	Number	1.1	1.2	1.3	1.2	1.2	1.3
Avg. amount applied	Lbs./ac.	73.38	71.24	84.43	74.56	94.36	92.74
Area with scouting for pests	Percent	na	na	na	85	na	na
Area under crop rotation	Percent	97	97	97	97	96	98
Area with cultivations for weed control	Percent	91	95	93	93	93	94
Area treated with purchased beneficial insects	Percent	na	na	na	na	na	na

na = not available. [1] For States included, see "Cropping Practices Survey" in the appendix. Source: USDA, ERS, Cropping Practices Survey data.

Table 4.4.2—Fruit and vegetable acreage treated with pesticides, major producing States, 1992/93 and 1994/95

	Planted acres[1]	States surveyed[2]	Area receiving application						Total application 1994/95		
			1992/1993			1994/1995			1994/1995		
			Herbicide	Insect-icide	Fungicide	Herbicide	Insect-icide	Fungicide	Herbicide	Insect-icide	Fungicide
	1,000 ac.	*No.*	*Percent of acres*						*1,000 lbs.*		
Fruit:											
Grapes, all types	796	6	64	66	93	74	67	90	1,193	3,970	32,551
Oranges	760	2	94	90	57	97	94	69	3,466	40,263	1,962
Apples, bearing	345	9	43	99	88	63	98	93	567	10,733	4,624
Grapefruit	147	2	93	93	85	92	89	86	618	9,185	1.420
Peaches, bearing	144	8	49	99	98	66	97	97	182	2,023	5,029
Prunes	94	1	40	93	84	46	73	84	64	842	398
Avocados	73	1	50	12	10	24	9	1	35	14	8
Pears	68	4	44	98	92	65	96	90	96	3,310	1,388
Cherries, sweet	47	4	45	94	87	61	92	93	56	777	655
Lemons	48	1	71	88	14	83	73	64	141	1,280	106
Cherries, tart	47	4	49	98	99	67	94	98	45	93	930
Plums	44	1	70	89	79	48	75	71	36	562	303
Olives	38	1	67	27	33	54	14	30	58	108	59
Nectarines	36	1	84	98	95	82	97	96	84	98	95
Blueberries	30	4	75	91	81	73	86	87	50	127	222
Vegetables:											
Sweet corn, proc.	503	7	92	75	19	94	66	9	1,623	254	59
Tomatoes, proc.	323	1	90	81	92	76	71	86	442	219	9,817
Greenpeas, proc.	203	6	91	49	1	93	50	*	251	42	4
Lettuce, head	191	5	68	97	76	60	100	77	127	631	524
Snap beans, proc.	173	9	95	68	55	91	58	41	449	139	65
Watermelon	166	6	37	53	71	41	45	64	68	136	681
Sweet corn, fresh	164	12	75	84	41	79	81	36	328	627	203
Onion	128	9	86	79	83	88	76	89	760	174	887
Broccoli	111	4	58	95	31	67	96	36	242	287	48
Tomatoes, fresh	104	8	75	95	86	52	94	91	114	710	3,417
Carrots	101	9	67	37	79	72	34	71	117	58	483
Cantaloupe	98	5	44	78	73	41	82	41	42	103	636
Cucumbers, proc.	83	9	74	34	32	77	48	30	95	41	49
Asparagus	81	5	86	64	28	91	70	23	205	100	59
Snapbeans, fresh	71	7	52	77	62	60	79	63	62	120	504

*Applied on less than 1 percent of the acres.

[1] Fruit producers were surveyed in 1993 and 1995; vegetable producers were surveyed in 1992 and 1994. Planted acreage in the major producing States surveyed is for 1994 for vegetables and 1995 for fruit.

[2] The survey was conducted in major producing States during both survey periods; the set of minor producing States that were surveyed was modified slightly between survey years for about one-third of the commodities. For States included, see "Chemical Use Survey" in the appendix.

Source: USDA, ERS and NASS, Chemical Use Survey data.

Insecticide use fluctuates with cycles of pest infestation, but is generally well under 10 percent of wheat area. Large populations of Russian wheat aphid and other insect pests in 1994 caused winter wheat farmers to treat nearly 10 percent of their acreage with insecticides (Padgitt, 1996). Because disease-resistant varieties are used to combat many wheat diseases, fungicides are normally applied to less than 5 percent of the wheat acres.

Cotton. Cotton is one of the most pesticide-intensive field crops grown in the United States. In 1995, 98 percent of cotton acreage received herbicides, 76 percent received insecticides, and 57 percent received other types of pesticides. Herbicides and insecticides account for about 76 percent of the pesticide applied to cotton, while plant growth regulators, defoliants, and other pesticides used to aid harvesting account for most of the remainder. Cotton diseases treated with a fungicide account for only 1 percent of all pesticides used on cotton.

Insect infestation on cotton is much greater than it is for corn, soybeans, or wheat, partly due to its longer growing season and the winter survival rates of insect eggs and larvae in warmer climates where it is grown. Although boll weevil eradication programs have been successful in several Southern States, tobacco budworms, cotton boll worms, thrips, and the boll weevil prevail in other States and require frequent treatments. About two-thirds of the cotton acres are treated for insect pests, often with repetitive treatments. Significant increases in insecticide use have occurred annually during the 1990's. The average quantity of insecticides applied per acre more than doubled between 1991 and 1994, while the average number of treatments increased from 3.1 to 5.7 and the number of different insecticide products increased from 2.3 to 3.5. In Louisiana and Mississippi, 10 or more insecticide treatments are applied during the growing season.

For weed control, most cotton is treated with a combination of pre-emergence and post-emergence herbicides. Unlike corn, soybeans, and wheat, no new low-rate herbicides have become available for cotton, and producers continue to rely on herbicides registered during the 1950's and 1960's.

Potatoes. Potatoes are among the most pesticide-intensive crops for all types of pesticides. Herbicides, insecticides, and fungicides are each used to treat 85 percent or more of potato acreage, and recently over half of the acres have also been treated with a soil fumigant, growth regulator, defoliant, or harvest aid. While the share of potato acres receiving any pesticide type did not change much between 1990 and 1995, the intensity of treatments did increase for all pesticide types. Fungicides, which are used to treat early and late blight and other diseases, accounted for the largest increase in pesticide treatments. The average number of fungicide treatments per acre and the application rate both doubled between 1990 and 1994. Soil fumigants and defoliants account for the largest total quantity of pesticides used on potatoes, but are applied to the smallest area.

Other Vegetables and Fruits. Orchards, vineyards, and vegetable farms generally have much higher net returns per acre than farms that specialize in field crop production, and fruit and vegetable growers have found it profitable to use insecticides and fungicides. Between 90 and 98 percent of the acreage of the 5 largest fruit crops--grapes, oranges, apples, grapefruit, and peaches--received at least one treatment with an herbicide, insecticide, or fungicide in 1995, and the majority of acres were treated with all three types (table 4.4.2). Herbicides, insecticides, and fungicides were used to treat 97, 94, and 69 percent of the U.S. orange acreage in 1995, for example, and 63, 98, and 93 percent of the apple acreage. For most fruit crops, the volume of insecticides and fungicides used is generally higher than the volume of herbicides used.

Among other vegetables, herbicides and insecticides were used on 94 and 66 percent of processing sweet corn, the largest vegetable crop, in 1994. Herbicides and fungicides were used on 76 and 86 percent of the second largest crop, tomatoes grown for processing. Pesticide surveys from the 1960's and 1970's also showed the majority of fruit and vegetable acreage receiving pesticides (Osteen and Szmedra, 1989).

Consumer expectations of cosmetically perfect fruits and vegetables, with no blemishes from insects or disease, fuels insecticide and fungicide use. And fresh-market vegetable acreage often receives more pesticides than the processing market crop. For example, a larger share of the fresh-market sweet corn and tomato acreage received fungicide and insecticide treatments than sweet corn and tomatoes grown for processing (table 4.2.2).

Regional differences in rainfall, humidity, soil types, and other growing conditions help determine the severity of pest problems and the intensity of pesticide use. Insecticide applications on grapes in 1994/95 ranged from 17 percent of the crop area in Washington to 96 percent in Michigan (table 4.4.3). Processing sweet corn receiving insecticides ranged from 41 percent in Washington to 82 percent in Illinois.

Pest problems, and the available alternatives for managing pests, vary over time as well as by crop and region. For the top three fruit crops—grapes, oranges, and apples—total area treated with pesticides increased or stayed about the same between 1992/93 and 1994/95 (table 4.4.3). However, insecticide and fungicide applications to total acreage of the two top vegetable crops—processing sweet corn and tomatoes—dropped. While insect and disease pressure may have been lighter during the second survey, the availability of alternatives may have also

Table 4.4.3—Pesticide application on selected fruit and vegetable crops, by major producing State, 1992/93 and 1994/95

Crop and State	Planted acres[1]	Area receiving applications					
		1992/1993			1994/1995		
		Herbicide	Insecticide	Fungicide	Herbicide	Insecticide	Fungicide
	1000 ac.	*Percent of acres*					
Fruit:							
Grapes, all types	796	64	66	93	74	67	90
California	701	62	67	94	73	68	92
Washington	34	72	39	52	77	17	35
New York	33	81	64	99	85	78	94
Michigan	12	90	97	100	93	96	100
Pennsylvania	11	72	59	52	99	93	99
Oregon	5	52	3	99	70	18	95
Oranges	760	94	90	57	97	94	69
Florida	563	98	96	69	98	96	77
California	197	94	90	57	92	86	46
Apples, bearing	345	43	99	88	63	98	93
Washington	153	45	100	85	66	99	88
New York	58	33	100	100	63	99	99
Michigan	54	54	99	100	68	100	100
California	40	46	92	71	48	86	88
Pennsylvania	22	34	100	100	66	98	98
Oregon	9	66	98	98	73	99	96
South Carolina	4	18	100	100	84	99	99
Vegetables:							
Sweet corn, proc.	503	92	75	19	94	66	9
Wisconsin	161	92	68	11	95	62	3
Minnesota	143	94	81	40	95	80	20
Washington	75	87	85	*	86	41	*
Oregon	49	90	60	*	98	63	*
Illinois	37	98	99	50	97	82	20
New York	33	92	60	**	98	66	3
Michigan	7	93	93	*	88	77	*
Tomatoes, proc.	323	90	81	92	76	71	86
California	318	90	81	92	76	71	86
Michigan	5	90	82	99	85	88	100

*Applied on less than 0.5 percent of the acres.
**Insufficient reports to publish percent of area receiving.
[1] Fruit producers were surveyed in 1993 and 1995, vegetable producers in 1992 and 1994; planted acreage in the listed State is for 1994-95.

played a role. A large U.S. food processor, for example, sought in the early 1990's to reduce the amount and frequency of pesticide use among its growers, and has been encouraging the use of Bt, parasitic wasps, mating-disrupting pheromones, disease-forecasting systems, and other biological and pesticide-reducing technologies (Orzalli, Curtis, and Bolkan, 1996).

Pesticide-Efficiency Tools

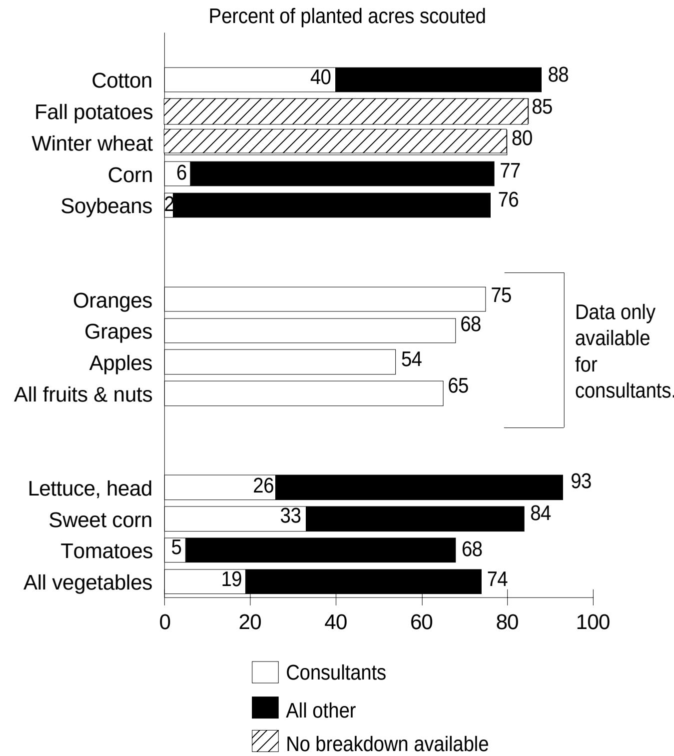
Entomologists have developed pest scouting, economic thresholds, and other tools to help producers determine when to make pesticide applications, which pesticides to use, and how much to use, and "expert systems" have integrated these tools into decision management software. Several new chemical-efficiency technologies—including precision farming and herbicide-tolerant crops—are just now being developed and commercialized. While these tools generally rely on pesticides, they may lower risks through lower rates, less toxic materials, or fewer applications.

Scouting and Economic Thresholds. Entomologists have been developing scouting techniques to monitor the populations of major insect and other arthropod pests for several decades. Field trials were conducted to determine the crop-damage functions associated with these pests in order to set economic thresholds--pest population levels above which economic damage to the crop would occur without pesticide application. These scouting techniques and thresholds were designed to replace routine, calendar-based insecticide applications.

While scouting techniques and thresholds have been developed for most major insect pests in agriculture, weed scientists and ecologists have only recently begun exploring whether economic thresholds are applicable for weed management (Coble and Mortensen, 1992). Economic thresholds are rarely used for plant pathogens since infections generally spread too quickly to use fungicides after the disease is detected. However, disease prediction models that result in disease advisories for some major fruit and field crops have been developed and commercialized.

Scouting and threshold use is widespread in specialty crop production (Vandeman and others, 1994). Nearly two-thirds of the U.S. fruit and nut acreage and nearly three-quarters of the vegetable acres in the surveyed States were scouted for insects, mostly by chemical dealers, crop consultants, and other professionals (table 4.4.4, fig. 4.4.1). Growers reported using thresholds as the basis for making pesticide treatment decisions on virtually all of these scouted acres (Vandeman and others, 1994). Potato growers reported that 85 percent of their acreage was scouted in 1993 (table 4.4.1), and thresholds were used in making nearly three-quarters of their insecticide application decisions. Growers of two-thirds to three-fourths of corn and soybeans reported scouting, mostly by themselves or a family member. Most of these growers reported using thresholds as well (Vandeman and others, 1994). Nearly 90 percent of the cotton acreage was scouted, including commercial scouting service on 40 percent of this acreage (table 4.4.1, fig. 4.4.1). Insect pests cause large economic losses in cotton production, and entomologists have been developing thresholds for these pests for several decades.

Figure 4.4.1--Use of scouting for pests, selected crops in major producing States, 1990's



Source: USDA, ERS, Cropping Practices and Chemical Use Surveys.

Application Tools. Producers use a variety of pesticide application techniques to make applications more efficient. For example, most farmers broadcast pesticides across the field, but an alternative technique--banding applications--can lower herbicide application rates substantially (Lin and others, 1995). However, mechanical cultivation to control weeds between rows is often required, and growers have not increased their use of banding during the 1990’s. About 14 percent of the U.S. corn area in surveyed States treated with herbicides in 1994 was banded, and about 6 percent of soybeans were banded. Other examples of efficiency tools include drip pans for spray equipment to catch "overspray," and the use of dwarf fruit trees, which require less pesticide spray material than full-size trees.

Expert Systems. “Expert systems” integrate information on pest density, economic thresholds, application methods, and other elements of pesticide use into a computer software package that helps the farmer determine when to make pesticide applications, which pesticides to use, and how much to use. For example, a threshold-based model for corn and soybeans (NebraskaHERB) determines whether it is cost-effective to manage weeds in a

Table 4.4.4—Use of selected biological and cultural pest management practices on fruit, vegetable, and nut crops, major producing States, 1990's

Crop	In surveyed States[1]	Scouting: Consultants	Scouting: Grower/ family member	Scouting: Chemical dealer	Scouting: Other	Scouting: Total	Biological methods[2]: Beneficial insects	Biological methods[2]: Habitat provision	Biological methods[2]: Pheromone traps[3]	Biological methods[2]: Resistant varieties	Cultural methods[2]: Water management	Cultural methods[2]: Field sanitation	Cultural methods[2]: Adjust planting dates
	1,000 ac. planted	*Percent of acres*											
Fruit:													
Grapes, all	730	68	na	na	na	na	18	na	14	31	41	64	na
Oranges	613	75	na	na	na	na	22	na	28	21	27	48	na
Apples	381	54	na	na	na	na	2	na	66	16	22	73	na
All fruits & nuts	3,251	65	na	na	na	na	19	na	37	22	31	60	na
Vegetables:[4]													
Sweet corn	640	33	22	2	27	84	*	na	17	na	7	na	8
Tomatoes	357	5	15	47	1	68	5	na	6	na	21	na	47
Lettuce, head	259	32	26	26	9	93	3	na	1	na	4	na	26
All vegetables	2,914	21	19	19	15	74	3	na	7	na	11	na	15
	No. growers surveyed	*Percent of surveyed growers*											
Certified organic vegetables:													
Sweet corn	64	**	91	0	3	94	46	67	na	80	33	na	56
Tomatoes	55	**	94	0	1	95	48	57	na	71	46	na	41
Lettuce, head	33	**	97	0	3	100	60	60	na	73	80	na	50
All vegetables	303	**	91	0	6	97	46	58	na	75	44	na	54

* Used on less than 0.5 percent. **Included in other. na = not available.

[1] Data is from the 1991 USDA Chemical Use Survey for fruits and nuts, the 1992 Survey for vegetables, and the 1994 Survey for certified organic vegetables. For major producing States surveyed, see "Chemical Use Survey" in the appendix.

[2] Use for any type of pest in 1991 and 1992, and for three specific types (insects, disease, or weeds) in 1994 (highest use for a specific type is shown).

[3] Reported for all uses (pest control and monitoring) in 1991 and 1994, and for control only in 1992.

[4] Includes fresh and processing crops.

Source: USDA, ERS and NASS, Chemical Use Survey data.

field, and identifies whether broadcast or band-applied herbicides or cultivation is the most cost-effective treatment. The Nebraska Extension Service reports use in Nebraska is small but growing (USDA, 1994). The use of "expert systems" (decision support) software is still well under 1 percent in U.S. corn and soybean production according to recent ERS surveys (Padgitt, 1996). Several university expert systems, which forecast diseases in some major fruit and vegetable crops, have recently become available commercially through IPM product suppliers, including the "Penn State Apple Orchard Consultant" and the University of Wisconsin's WISDOM software.

Precision Farming. Precision farming is an emerging technology that may allow a more efficient application of inputs by using tractor-mounted yield monitors, satellite images, GIS, and other developing information technologies to tailor inputs to the different conditions in each field. Soil leachability, pH, and other characteristics often vary, sometimes substantially, within the farm field, and better tailoring of inputs to site-specific field conditions can increase crop yields. Most precision farming has addressed nutrient management, but research on pest management using this technology is emerging. Recent industry surveys indicate that only a small number of corn growers are experimenting with precision farming. The yield monitors and equipment necessary for many other crops, especially vegetable crops, have not been developed yet.

The potential for this technology to increase yields or to reduce pesticide use is being examined by USDA, the chemical industry, and other organizations. The few existing studies on the potential of precision farming to provide environmental benefits have been inconclusive about its effect on pesticide use.

Bioengineered Herbicide Tolerance. Seed and chemical companies have expanded research and development on plant biotechnology because of the increasing costs to develop chemical pesticides that meet human health and environmental regulations and are sufficiently toxic to kill target pests (Ollinger and Fernandez-Cornejo, 1995). Compared with traditional genetic plant breeding, plant biotechnology reduces the time required to identify desirable traits. In addition, by inserting into the plant a gene that imparts some desirable properties, biotechnology allows a precise alteration of a plant's traits, facilitating the development of plant characteristics not possible through traditional plant breeding techniques. This technology allows researchers to target a single plant trait, which decreases the number of unintended characteristics that may occur with traditional breeding techniques. The development of genetically modified plants takes about 6 years and costs about $10 million, while a chemical pesticide takes an average of 11 years at a cost of $50-$70 million to develop (Ollinger and Fernandez-Cornejo, 1995).

A number of seed and chemical companies have been developing plant varieties with resistance to particular herbicides (table 4.4.5). Monsanto has developed a soybean variety that is not damaged by Monsanto's popular herbicide glyphosate (Roundup) and similar glyphosate-tolerant varieties are being developed for canola, cotton, corn, sugar beets, and rapeseed oil. This technology could provide growers with an incentive to use pesticides that are effective at lower rates than other pesticides.

Concerns about this technology include the possibility of accelerated weed resistance as well as the toxicity of the herbicide products that crop tolerance is developed for. Danish scientists recently reported that the genes for herbicide resistance in transgenic oilseed rape had moved to field mustard, a wild relative, and that this weed demonstrated herbicide resistance (Kling, 1996).

Table 4.4.5—Bioengineered crop varieties approved for commercial production, 1994-96

Approval date[1]	Applicant	Crop
Herbicide-tolerant varieties:		
2/5/94	Calgene	Cotton
5/19/94	Monsanto	Soybean
6/22/95	AgrEvo	Corn
7/11/95	Monsanto	Cotton
12/19/95	Dekalb	Corn
1/26/96	Dupont	Cotton
7/31/96	AgrEvo	Soybean
Herbicide-tolerant varieties with other traits:		
2/22/96	Plant Genetic Systems	Corn[2]
(8/30/96)[3]	Monsanto	Corn[4]
Insect-resistant varieties:		
3/2/95	Monsanto	Potato
5/17/95	Ciba-Geigy	Corn
6/22/95	Monsanto	Cotton
8/22/95	Monsanto	Corn
1/18/96	Northrup-King	Corn
5/3/96	Monsanto	Potato
(8/14/96)[3]	Dekalb	Corn
Virus-resistant varieties:		
12/7/94	Upjohn	Squash
6/14/96	Asgrow	Squash
(2/20/96)[3]	Cornell University	Papaya

[1] Date the Animal Plant Health Inspection Service (APHIS) determined that these field-tested crop varieties had no potential for plant pest risk and need no longer be regulated.
[2] Includes a male sterility trait.
[3] Date APHIS received the petition for approval; non-regulated status is still pending.
[4] Includes an insect resistant trait.
Source: USDA, ERS, based on information provided by APHIS.

Biological Pest Management

According to a recent Office of Technology report, the market for biologically based pest controls is small but fast-growing. The market value of biologically based products—natural enemies, pheromones, and microbial pesticides—sold in the United States during the early 1990's was estimated at $95-$147 million, 1.3 to 2.4 percent of the total market for pest control products (U.S. Congress, 1995). At least 30 commercial firms or "insectaries" produce natural enemies. Even though the current market for biological products is growing and large pest control companies are beginning to participate, the market is still so small that biologicals are unlikely to replace pesticides in the foreseeable future unless major research and development activities are started (Ridgway and others, 1994).

Biological pest management includes the use of pheromones, plant regulators, and microbial organisms such as *Bacillus thuringiensis* (Bt), as well as pest predators, parasites, and other beneficial organisms. EPA currently regulates biochemicals and microbial organisms and classifies them as "biorational pesticides." Another major biological tactic has been to breed crop varieties with "host plant resistance" to insects and disease.

Microbial Pesticides and Pheromones. Biorational pesticides, such as Bt and pheromones, have differed significantly from chemical pesticides in that they have generally managed rather than eliminated pests, have had a delayed impact, and have been more selective (Ollinger and Fernandez-Cornejo, 1995). For example, microbial pesticides have not been successful as herbicides because target weeds are replaced by other weeds not affected by the microbial pesticide.

Among the most successful microbials has been Bt, which kills insects by lethal infection. Growers have dramatically increased their use of Bt during the 1990's, especially under biointensive and resistance-management programs, because of its environmental safety, improved performance, cost competitiveness, selectivity, and activity on insects that are resistant to chemical pesticides. It is one of the most important insect management tools in certified organic production. Bt was used on more than 1 percent of the acreage of 12 fruit crops in 1995, up from 5 crops in 1991 (table 4.4.6). Between 12 and 23 percent of the apple, plum, nectarine and blackberry acreage received Bt applications in 1995, and it was applied on over half of the raspberry acreage. Among vegetable crops, the acreage treated with Bt increased for 13 of the 20 crops surveyed by USDA between 1992 and 1994, and was used on about half or more of the cabbage, celery, and eggplant acreage. Bt has been used on only a couple of field crops. Corn acreage treated with Bt was steady at 1 percent in 1994 and 1995, while treated cotton increased from 5 percent in 1992 to 9 percent in 1994 and 1995.

New Bt strains with activity on insects not previously found to be susceptible to Bt have been discovered in recent years. Current research is devoted to improving the delivery of Bt to pests and to increasing the residual activity and efficacy of Bt.

Pheromones are used to monitor populations of crop pests and to disrupt mating in organic systems and some IPM programs. Pheromones were used on 37 percent of fruit and nut crops acreage to monitor and control pests and on 7 percent of vegetable acreage to control pests (use for monitoring was not included in this survey) (table 4.4.4).

Table 4.4.6—Agricultural applications of *Bacillus thuringiensis* (Bt), selected crops in surveyed States, 1991-95

Crop[1]	1994/95 planted acres[2]	Area receiving application				
		1991	1992	1993	1994	1995
	1,000 acres	*Percent of acres*				
Field crops:						
Corn (17 States)	64,105	*	*	*	1	1
Cotton, upland	11,650	*	5	8	9	9
Fruit:						
Grapes	796	*	-	2	-	6
Oranges	760	2	-	7	-	3
Apples, bearing	345	3	-	13	-	12
Peaches	144	*	-	3	-	5
Prunes	94	*	-	*	-	9
Pears	68	*	-	1	-	2
Sweet cherries	47	*	-	8	-	9
Plums	44	*	-	*	-	14
Nectarines	36	*	-	10	-	22
Blueberries	30	11	-	8	-	5
Raspberries	11	49	-	45	-	52
Blackberries	4	18	-	*	-	23
Vegetables:						
Tomatoes, proc.	323	-	6	-	5	-
Lettuce, head	191	-	18	-	20	-
Sweet corn, fresh	164	-	3	-	3	-
Onion	128	-	*	-	1	-
Broccoli	111	-	7	-	14	-
Tomatoes, fresh	104	-	31	-	39	-
Cantaloupe	98	-	32	-	8	-
Snap beans, fresh	71	-	20	-	29	-
Cabbage, fresh	70	-	48	-	64	-
Bell peppers	61	-	35	-	37	-
Lettuce, other	60	-	39	-	22	-
Cauliflower	54	-	12	-	20	-
Cucumbers, fresh	51	-	19	-	22	-
Strawberries	46	-	24	-	33	-
Celery	36	-	51	-	61	-
Honey dew	26	-	28	-	10	-
Spinach	10	-	13	-	21	-
Eggplant	4	-	13	-	48	-

* Applied on less than 0.5 percent of the acres. - = Not a survey year for that commodity.

[1] Bt use was too small to report on soybeans, wheat and potatoes, and on other surveyed fruit and vegetable crops.

[2] Planted acres in the surveyed States.The survey accounted for between 79 and 90 percent of U.S. total planted corn acreage, between 70 and 78 percent of the total Upland cotton acreage, and over 70 percent of fruit and vegetable acreage. For major producting States included, see "Chemical Use Survey" in the appendix.

Source: USDA, ERS and NASS, Chemical Use Survey data.

Beneficial Organisms. Natural enemies of crop pests, or "beneficials," may be imported, conserved, or augmented. Many crop pests are not native to this country, and USDA issues permits for the natural enemies of these pests to be imported from their country of origin. Natural enemy importation and establishment, also called classical biological control, has been undertaken primarily in university, State, and Federal projects; 28 States operate biocontrol programs and most have cooperative efforts with USDA agencies (U.S. Congress, 1995). Some crop pests, such as the woolly apple aphid in the Pacific Northwest, have been largely controlled with this method.

Natural enemies may also be "conserved" by ensuring that their needs—for alternate hosts, adult food resources, overwintering habitats, a constant food supply, and other ecological requirements—are met, and by preventing damage from pesticide applications and other cropping practices (Landis and Orr, 1996). Over half of the certified organic vegetable growers in 1994 were providing habitat for beneficials (table 4.4.4).

"Augmentation" boosts the abundance of natural enemies (native and imported) through mass production and inundative or inoculative releases in the field (Landis and Orr, 1996). An inundative release—the most common augmentation method—can be timed for when the pest is most vulnerable and is used when the natural enemy is absent or when its response to the pest pressure is insufficient. An inoculative release may be made in the spring for a natural enemy that cannot overwinter in order to establish a population. Unlike the importation and conservation approaches, the augmentation method generally does not provide permanent suppression of pests. Beneficial insects were used on 3 and 19 percent of the surveyed vegetable and fruit acreage in the early 1990's, and by nearly 46 percent of the certified organic vegetable growers (table 4.4.4).

A small but increasing number of companies are supplying natural enemies of insects, weeds, and other pests to farmers. For greenhouse and agricultural crop production, most natural enemies being sold—such as beneficial insects, predatory mites, parasitic nematodes, and insect egg parasites—are used for managing pest mites, caterpillars, citrus weevils, and other insect and arthropod pests. However, a number of natural enemies—musk thistle defoliating weevils, for example—are being sold for managing weeds on rangeland and uncultivated pastures (Poritz, 1996).

The California Environmental Protection Agency has published a list of commercial suppliers of natural enemies in North America since 1979, and the number has increased steadily. In 1994, 132 companies were listed, mostly in the United States, offering over 120 different organisms for sale (Hunter, 1994).

Host Plant Resistance. Corn and soybean breeding for genetic resistance to insects, disease, and other pests has been the research and development focus of major seed companies for many decades (Edwards and Ford, 1992). U.S. soybean acreage, for example, receives virtually no fungicides because of the effectiveness of the disease-resistance soybean cultivars that have been developed.

The use of classical breeding programs is now being augmented with new plant breeding efforts using transgenic and other genetic engineering techniques. In March 1995, the EPA approved, for the first time, a limited registration of genetically engineered plant pesticides to Ciba and Mycogen Plant Sciences, and in August 1995, granted conditional approval for full commercial use of a transgenic pesticide to combat the European corn borer (EPA, 1995). This plant pesticide, Bt corn, is produced when the genetic information related to insecticidal properties is transferred from the Bt bacterium to the corn plant. This technology could reduce the need for conventional chemical insecticides in corn production. In 1995, 26 percent of U.S. corn acreage was treated with insecticides (table 4.4.1), and corn borer is one of the top insect pests targeted for treatment.

However, since these new corn varieties contain natural genes and genes produced from the soil bacteria Bt, many scientists are concerned that the new corn will hasten pest immunity to Bt. This is especially a concern for the growing number of producers who rely on the foliar-applied Bt, and has led the EPA to approve the new pesticides conditional on the monitoring for pest resistance and the development of a management plan in case the insects become resistant.

The techniques used for developing disease-resistant plants are similar to the immunization of humans by vaccines. Small amounts of plant viruses are inserted into the plants, which subsequently become immune to the diseases (Salquist, 1994). The plants are capable of passing this trait from generation to generation. For example, researchers have developed squash varieties that are naturally virus-resistant, thus preventing insect-borne viruses that can destroy up to 80 percent of the squash crop. A number of seed and chemical companies and one university have been field-testing insect- and virus-resistant plants, developed with these genetic engineering techniques, for several major field crops and vegetables (table 4.4.5).

While most classical breeding programs have focused on pests resistant to chemicals or treatments that were too expensive (Zalom and Fry, 1992b), consumer concern over pesticides in agricultural products has prompted biotechnology companies to enter the genetically engineered plant market. As agricultural biotechnology products attain commercial success, some private investment funding may shift from the smaller pharmaceutical markets toward agricultural crop protection (Niebling, 1995). On the other hand, consumer acceptance of the bioengineered Bt corn, Bt cotton, and other genetically engineered crops has not yet been demonstrated in major U.S. markets. A 1992 survey of U.S. consumer attitudes about food biotechnology, published by North Carolina State University, found that most consumers want information on labels about various food characteristics, including the use of biotechnology (Hoban and Kendall, 1993).

APHIS (Animal Plant Health Inspection Service) has approved or acknowledged 638 field trials for insect-resistant varieties since 1987 (24 percent of the total field trials approved or acknowledged), 286 field trials to test viral resistance (11 percent), and 94 field trials for fungal resistance (3.5 percent).

Cultural Pest Management

A number of production techniques and practices—including crop rotation, tillage, alterations in planting and harvesting dates, trap crops, sanitation procedures, irrigation techniques, fertilization, physical barriers, border sprays, cold air treatments, and habitat provision for natural enemies of crop pests—can be used for managing crop pests. Cultural controls work by preventing pest colonization of the crop, reducing pest populations, reducing crop injury, and enhancing the number of natural enemies in the cropping system (Ferro, 1966).

These ecosysem-based pest control techniques are knowledge-intensive, and widespread adoption by growers would require major new funding for basic and applied research (National Academy of Sciences). The National Research Council also suggests that the base of research necessary to develop and implement cultural pest management and other ecosystem-based pest management techniques is much greater than for synthetic chemical pesticides.

Crop rotation is one of the most important of the current cultural techniques. Eighty percent of U.S. corn acreage was in rotation with other crops in 1995, up slightly from 76 percent in 1990 (table 4.4.1). Over half of the corn was being grown in rotation with soybeans and about 15 percent with other row crops (see chapter 4.3, *Cropping Management*, for more detail on cropping patterns). Ninety percent of soybeans were grown in crop rotations in 1995. Corn producers rotating corn with other crops used insecticides less frequently than did those planting corn 2 years in succession (11 percent of acres versus 46 percent). Corn is often grown as a monocrop in heavy livestock areas and where climate limits the soybean harvest period (Edwards and Ford, 1992).

Crop rotation was much less prevalent for cotton, which has among the highest per-acre returns of U.S. field crops. Less than one-third of the cotton producers use this technique (table 4.4.1). Crop rotation in wheat varies with the type being grown; it was used on 77 percent of the spring crop but only 57 percent of the winter wheat crop in 1995. Crop rotation was used for virtually all of the potato acreage.

Cultivation for weed control is widely practiced for field crops, mostly in conjunction with herbicide use. Almost all of the potato and cotton acreage received cultivations in 1995, along with 66 percent of corn. For soybeans, cultivations dropped from 67 percent in 1990 to 41 percent in 1995 (table 4.4.1).

Field sanitation and water management (see glossary) are widely used on fruit and nut crops, with 60 percent and 31 percent of the acreage under these practices in the early 1990's (table 4.4.4). For vegetable crops, planting dates were adjusted as a cultural control on 15 percent of the surveyed crop area. Water management was used by 44 percent of the certified organic vegetable producers, and over half were using adjusted planting dates to manage pests.

Research on new cultural techniques such as solarization—heating the soil to kill crop pests—continues to emerge. However, most cultural practices do not involve a marketable product, and research and development depends almost entirely on public sector funding (U.S. Congress, 1995). While cultural practices may be effective for controlling pests, reducing pesticide use, and lowering input costs, these techniques require a knowledgeable producer and growers may not be getting adequate information about them.

Pest Management Programs and Initiatives

Pest management systems in the future will emerge against the backdrop of continued consumer preference for fewer farm chemicals and scientific uncertainty about the ecological and health impacts of chemical use. In addition to State and Federal pesticide regulations, farmers' pest management choices will be influenced by the costs and risks of pesticides and alternatives, the market for green products, and other factors. USDA, EPA, and other government agencies have initiated a number of programs to encourage biological and cultural pest management, including biointensive IPM research and promotion, areawide pest management, regulatory streamlining for biologicals, and national organic standards development.

IPM Research and Promotion

On September 22, 1993, the EPA, USDA, and the Food and Drug Administration (FDA) presented joint testimony to Congress on a comprehensive interagency effort designed to reduce the pesticide risks associated with agriculture. The three goals of this effort are to (1) discourage the use of higher risk products, (2) provide incentives for the development and commercialization of safer products, and (3) encourage the use of alternative control methods which decrease the reliance on toxic and persistent chemicals (Browner and others, 1993). This joint testimony also expressed support for integrated pest management (with a goal of IPM programs on 75 percent of total U.S. crop acreage by the year 2000), ecosystem-based programs to reduce pesticide use, market-based incentives such as reduced-pesticide use food labels, and other efforts to help reduce pesticide risks.

State Extension Service IPM programs are overseen by designated IPM coordinators, mostly entomologists who focus on developing interdisciplinary pest management programs (Grey, 1995). Over half of U.S. farmers are using a minimum level of IPM—including scouting for insect pests and applying insecticides when economic thresholds are reached (Vandeman and others, 1994)—as opposed to the conventional pesticide application method of preventative, calendar-based spraying. Economic and environmental studies have reported mixed results in terms of the impacts of IPM scouting and thresholds on pesticide use (Rajotte and others, 1987; Mullen, 1995; and Ferguson and Yee, 1995; Fernandez-Cornejo, 1996).

The first national study of biologically based IPM in the early 1990's, jointly sponsored by USDA and EPA, concluded that dozens of technical, institutional, regulatory, economic, and other constraints need addressing in order to achieve broader adoption (Zalom and Fry, 1992a). Three constraints were identified by all commodity groups: (1) lack of funding and personnel to conduct site-specific research and demonstrations; (2) producer perception that IPM is riskier than conventional methods, more expensive, and not a shortrun solution; and (3) educational degree programs that are structured toward narrow expertise rather than broad knowledge of cropping systems (Glass, 1992).

The current IPM initiative in USDA, which has been partly funded by Congress, attempts to address the funding constraint and need for demonstrations and highlights stakeholder involvement in priority setting for IPM research (Jacobsen, 1996). A few IPM research projects have started to examine biocontrols and cultural practices for several commodities, especially those that may not have adequate pest management alternatives because of current or pending EPA regulatory actions or voluntary pesticide registration cancellations.

Areawide Pest Management Systems

USDA is also developing and implementing an areawide pest management approach—through partnerships with growers, commodity groups, government agencies, and others—to contain or suppress the population levels of major insect pests in agriculture over large definable areas, as opposed to on a farm-to-farm basis (Calkins and others, 1996). Biological and cultural methods are the focus of most of these areawide programs.

Some biological control tactics, such as sterile insect releases, are most effective if implemented on a large area that encompasses many farms (U.S. Congress, 1995). For example, corn rootworm is a highly mobile pest as an adult and management is expected to be more effective over a large area. The goals of the program are to provide more sustainable pest control, at costs competitive with insecticide-based programs, and to reduce the use of chemical insecticides in agriculture. One successful biologically based areawide program was launched against the screwworm, a major parasitic pest of livestock, pets, and humans. USDA began releasing sterile male screwworm flies into wild populations in the 1950's, and by the early 1980's the screwworm became the only pest successfully eradicated from the United States (U.S. Congress, 1995).

USDA currently has five biologically based areawide IPM projects in various stages of evaluation, pilot testing, and large area implementation (table 4.4.7). The oldest, the Areawide Bollworm/Budworm Project in Mississippi, was initiated in 1987. Under this project, serious insect pests of Delta crops, especially cotton, were managed successfully with natural insect pathogens in small field tests. The project went into a large-area testing phase with 215,000 acres in 1994 and 1995.

Another areawide IPM project, the regional Coddling Moth Areawide Management Program (CAMP), uses pheromone mating disruption to control the coddling moth, the primary insect pest of apples in California, Oregon, and Washington. CAMP is a cooperative effort between ARS and three universities, and it aims to reduce organophosphate insecticide use by 80 percent in these apple- and pear-producing States (Kogan, 1996). The coddling moth had grown resistant to the organophosphate insecticide which required growers to triple applications of that chemical (Flint and Doane, 1996). Pilot testing of the project began in 1995 on five sites, and initial results indicate substantial reductions in organophosphate use and a positive response from growers (Kogan, 1996).

Two projects are examining the areawide use of attractants—semiochemical bait with tiny amounts of insecticide—to control corn rootworm in the Midwest, and Mexican corn rootworm and cotton bollworn in Texas and other States (Calkins and others, 1996). The Federal Crop Insurance Corporation has issued a crop insurance endorsement to cover any crop losses that might occur in testing sites.

Regulatory Streamlining for Alternatives

The EPA has facilitated the development of biorational pesticides by establishing a tier approval system in which, under some circumstances, several tests are waived. These reduced regulation costs have helped lower the development costs of biopesticides, which are currently estimated at around $5 million per product, compared with about $50-$70 million for a chemical pesticide (Ollinger and Fernandez-Cornejo, 1995).

The EPA is also making the regulation of biorational pesticides less stringent than that of chemical pesticides. For example, Lepidopteran pheromones may now be used experimentally on up to 250 acres without an experimental-use permit and are exempted from a food tolerance measure (*Pesticides & Toxic Chemical News*).

The EPA has also facilitated the use of minimum-risk alternatives to toxic pesticides by establishing a process for exemption from costly FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) requirements. Thirty-one substances (see box) deemed to pose insignificant risks to human health and the environment have recently been deregulated. EPA considered whether the substances were common foods, had a nontoxic mode of action, had FDA recognition as safe, had no information showing significant adverse effects, persistence in the environment and other factors. Supporters of the draft proposal on exemptions felt that deregulation of these substances would particularly benefit small businesses and the organic industry and supported the expansion of this list in the future, while opponents were concerned about product effectiveness (U.S. EPA, 1996a).

National Organic Standards, Certification, and Ecolabels

Organic farming systems focus on biological and cultural methods for pest management and virtually exclude the use of synthetic chemicals. In 1990, Congress passed the Organic Foods Production Act to provide consistent national standards to consumers for

Deregulated Minimum-Risk Pesticides

The following minimum-risk pesticides, mostly from common food substances, were exempted from costly Federal Insecticide, Fungicide, and Rodenticide Act requirements by the U.S. Environmental Protection Agency in a 1996 ruling: castor oil (U.S.P. or equivalent), cedar oil, cinnamon and cinnamon oil, citric acid, citronella and its oil, cloves and clove oil, corn gluten meal, corn oil, cottonseed oil, dried blood, eugenol, garlic and garlic oil, geraniol, geranium oil, lauryl sulfate, lemongrass oil, linseed oil, malic acid, mint and mint oil, peppermint and peppermint oil, 2-phenethyl propionate (2-phenylethyl propionate), potassium sorbate, putrescent whole egg solids, rosemary and rosemary oil, sesame and sesame oil, sodium chloride (common salt), sodium lauryl sulfate, soybean oil, thyme and thyme oil, white pepper, and zinc metal strips.

Source: EPA, 1996a.

Table 4.4.7—Implementation status of USDA's biologically-based areawide projects[1]

Project and objectives	Methods	Extent of implementation	Preliminary results
Coddling Moth, Pacific Northwest (Apples, pears) *Objective* - reduce broad spectrum neurotoxic insecticide use and maintain yields	Mating disruption Resistant cultivars Sanitation Natural enemies Early season Bt Sterile males	1995-1996: Randall Island, CA Medford, OR Yakima, WA Howard Flats, WA Orovill, WA 1997 planned: 5 additional sites	Late-season pesticide use declined Natural enemies increased Secondary pests declined Fruit damage was below 0.1% economic threshold 1st generation moths were reduced 80% Input costs were higher
Western Corn Rootworm Northern Corn Rootworm, Midwestern U.S. (Corn) *Objective* - reduce insecticide use and area treated, maintain yields, and reduce pest populations	Monitoring Semiochemical traps Semiochemical bait (includes tiny amounts of carbaryl)	1996: Brookings, SD 1997 planned: Illinois and Indiana Iowa Kansas	90% or more of the adults were killed (below threshold level) Natural enemies increased
Mexican Corn Rootworm, Texas & Oklahoma (Corn) *Objective* - reduce insecticide use and area treated; maintain or increase yields	Monitoring Semiochemical traps Semiochemical bait (includes tiny amounts of carbaryl)	1996: Bell County, TX 1997 planned: Bell County, TX	Adult population reduced below threshold levels; larvae will be assessed next spring No impact on beneficials Increased management costs offset by decreased input costs
Cotton Bollworm & Tobacco Budworm, Mississippi (Cotton) *Objective* - reduce insecticide use and area treated, maintain yields, and reduce pest populations	Monitoring with pheromone traps Insect virus (Gemstar) used on early-season weed hosts	1990-93: Mississippi (0-64,000 acres)[2] 1994-95: Mississippi (215,000 acres) 1996: Mississippi (25,000 acres) 1997 planned: Mississippi (215,000 acres) 1998 planned: Mississippi (850,000 acres)	More than 70% of moths killed Reduced insecticide use Yields were maintained Input and management costs were lowered

[1] USDA's Agricultural Research Service (ARS) is administering these projects through partnerships with other Federal agencies, universities, commodity associations, and other stakeholder groups.

[2] Pilot test acreage varied due to changes in funding and experiment design, and testing was cancelled one year because of severe flooding.

Source: USDA, ERS, based on Calkins and others, 1996; Kogan, 1994; and personal communication with Carrol Calkins, USDA-ARS, Yakima, WA, Laurence Chandler, USDA-ARS, Brookings, South Dakota; James Coppedge, USDA-ARS, College Station, Texas, and Dick Hardee, USDA-ARS, Stoneville, Mississippi.

organic production and processing methods. This legislation requires that all except the smallest organic growers be certified by a State or private agency accredited under national standards currently being developed.

The National Organic Standards Board, which was appointed by USDA to help implement the Act, currently defines organic agriculture as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimum use of off-farm production inputs, on management practices that restore and enhance ecological harmony, and on practices that maintain organic integrity through processing and distribution to the consumer" (Ricker, 1996). USDA is expected to publish the draft national organic standards in the Federal Register in 1997.

Organic Production. National data indicate a growing organic niche in the U.S. farm sector. A recent survey of public and private organic certifications indicated that there were at least 4,050 certified organic farms in the United States in 1994 with over a million acres in organic production (Dunn, 1995). And these statistics underestimate the number of U.S. growers using organic production methods, since the growers must farm organically for at least 3 years before they can certify their production under most certification organizations.

About 1 percent of the total U.S. fruit and vegetable acreage is organic, a higher proportion than for field crops, livestock feed, cotton, and other commodity sectors. California, the largest fruit and vegetable producing State, reports that organic farmers account for about 2 percent of its 80,000 farmers (White, 1994).

Few case studies have examined yields, input costs, income, and other characteristics of organic production. A review of the economic literature published in the 1970's and 1980's concluded that the "variation within organic and conventional farming systems is likely as large as the differences between the two systems," and found mixed results in the comparisons for most characteristics (Knoblauch, Brown, and Braster, 1990). Organic price premiums are key in giving organic farming systems comparable or higher whole-farm profits than conventional systems (Klonsky and Livingston, 1994; Batte, Forster, and Hitzhusen, 1993).

Organic agriculture is the most thoroughly documented system of ecological pest management in the United States. At least 11 States and 33 private agencies in the United States offer certification services to organic growers to ensure they are using the ecologically based standards associated with organic farming systems. California Certified Organic Farmers is a private certification organization and the oldest certifier in the Nation.

Certified Organic Labels. Over half the States have laws that regulate the production and marketing of organic food, and about half the States require State or private certification of products and operations to ensure that they are using only approved materials and practices. National standards under development in USDA are expected to facilitate international trade as well as enhance consumer confidence in organic food commodities.

Organic food products account for only about 1 percent of total retail food sales, but organics are one of the fastest growing segments of the industry. Consumer demand for organic food products has increased throughout the 1990's. Retail sales of fresh and processed organic food products reached $2.8 billion in 1995, and have increased over 20 percent annually since 1989 (*Natural Foods Merchandiser*, 1996). Increases in the number of large-format natural food stores, supermarket organic sections, export markets and direct-marketing outlets, as well as the expanding variety of organic foods, have fueled this growth. Organic products are labeled at retail in a variety of ways, including stickers, labels, signs, and other methods that indicate the certification organization or give other information.

Voluntary Environmental Standards. In addition to stronger pesticide regulations over the last decade, voluntary codes for environmental stewardship and responsible pesticide use in agriculture have begun to emerge. These codes are instituted by the private sector, enforced by firms themselves, use sanctions such as peer pressure for compliance, focus on life-cycle impacts, emphasize management systems, and let firms define their own performance standards. They can shift some of the environmental management costs to the private sector, expand a firm's environmental focus beyond the scope of regulation, help a firm integrate environmental and business objectives, and foster long-term changes in a firm's environmental consciousness (Nash and Ehrenfeld, 1996).

The Pesticide Environmental Stewardship Program was initiated in 1992 by EPA, USDA, and FDA to facilitate this type of voluntary approach, inviting organizations that use pesticides or represent pesticide users to join as partners (U.S. EPA, 1996b). Partners agree to implement formal strategies to reduce the use and risk of pesticides and to report regularly on progress. Membership in this stewardship program has grown to 41 partners, including many commodity groups across the country, and represents at least 45,000 pesticide users. The California Department of Agriculture has established a similar program, the IPM Innovators Program, to recognize individuals and groups that have demonstrated leadership in voluntarily implemented systems that reduce pesticide risks (Brattesani and Elliott, 1996) and to raise the environmental consciousness of other groups that use pesticides and inspire them to voluntarily adopt similar activities. Also, some States are examining the potential benefits of IPM certification, while Massachusetts is already operating a "Partners with

GLOSSARY

Chemical Methods

Banded pesticide application—the spreading of pesticides (herbicides, insecticides, or fungicides) over, or next to, each row of plants in a fields. Banding herbicides often requires row cultivation to control weeds in the row middles.

Broadcast pesticide application—the spreading of pesticides (herbicides, insecticides, or fungicides) over the entire surface area of the field.

Economic thresholds—levels of pest population which, if left untreated, would result in reductions in revenue that exceed treatment costs. The use of economic thresholds in making pesticide treatment decisions requires information on pest infestation levels from scouting.

Pesticides—the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) defines a pesticide as "any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant."

Pre-emergence herbicide—herbicides which are applied before weeds emerge. Pre-emergence herbicides have been the foundation of row-crop weed control for the past 30 years.

Post-emergence herbicides—herbicides which are applied after weeds emerge. Post-emergence herbicides are considered more environmentally sound than pre-emergence herbicides because they have little or no soil residual activity.

Scouting—checking a field for the presence, population levels, activity, size, and/or density of weeds, insects, or diseases. A variety of methods can be used to scout a field. Insect pests, for example, can be scouted by using sweep nets, leaf counts, plant counts, soil samples, and general observation.

Cultural Methods

Crop rotation—alternating the crops grown in a field on an annual basis, which interrupts the life cycle of insect pests by placing them in a non-host habitat.

Planting and harvesting dates—alterations in planting date and harvest date to avoid damaging pest infestations. Delayed planting of fall wheat seedlings may help avoid damage from the Hessian fly, for example.

Sanitation procedures—removing or destroying crops and plant material that are diseased, provides overwintering pest habitat, or encourages pest problems in other ways.

Tillage—can destroy pests in a variety of ways, for example, by directly destroying weeds and volunteer crop plants in and around the field.

Water management—water can be used as a pest management technique either directly, by suffocating insects, or indirectly, by changing the overall health of the plant.

Biological Methods

Beneficials—organisms that are pest predators and parasites and weed-feeding invertebrates that are used to control crop pests and weeds.

Habitat provision for natural enemies—growing crops and/or developing wild vegetative habitats to provide food (pollen, nectar, non-pest arthropods) and shelter for the natural enemies of crop pests.

Biochemical agents—include semiochemicals, plant regulators, hormones, and enzymes.

***Bacillus thuringiensis*, Bt**— bacteria that is used to control numerous larva, caterpillar, and insect pests in agriculture; *Bacillus thuringiensis* varieties *kurstaki* and *Bacillus thuringiensis* varieties *aizawai* are commonly used strains. In addition, some new varieties of corn contain natural genes and genes produced from the soil bacteria Bt to give them host-plant resistance to certain insect pests.

Gemstar— naturally occuring *Helicoverpa zea* nuclear polyhedrosis virus.

Microbial pest control agents—bacteria, such as *Bacillus thuringiensis*, viruses, fungi, and protozoa and other microorganisms or their byproducts.

Semiochemicals—pheromones, allomones, kairomones, and other naturally or synthetically produced substances that modify insect behavior.

Trap cropping—planting a small plot of a crop earlier than the rest of the crop in order to attract a particular crop pest; the pests are then killed before they attack the rest of the crop.

Sterile male technology—the male of the pest species is produced with inactive or no sperm, and is used to disrupt reproduction in the pest population.

Nature" program to recognize growers who follow a set of IPM certification guidelines (Van Zee, 1992).

Author: Catherine Greene, (202) 219-0466 [cgreene@econ.ag.gov]. Contributors: Jorge Fernandez-Cornejo, Merritt Padgitt, Sharon Jans, and Sarah Lynch.

References

Alavanja, M.C.R., A. Blair, S.B. McMaster, and D.P. Sandler (1993). "Agricultural Health Study: A Prospective Study of Cancer and Other Diseases Among Men and Women in Agriculture," National Cancer Institute, U.S. Environmental Protection Agency, and the National Institute of Environmental Health Sciences, Oct. 25 (Revisions Dec. 16).

Alavanja, Michael C. R., Dale P. Sandler, Suzanne B. McMaster, Shelia Hoar Zahm, Cheryl J. McDonnell, Charles F. Lynch, Margaret Pennybaker, Nathaniel Rothman, Mustafa Dosemeci, Andrew E. Bond, and Aaron Blair (1996). "The Agricultural Health Study," *Environmental Health Perspectives*, 104: 362-369.

AgriSystems International (1996). *International Organic Markets Report 1996*. Agrisystems International, Wind Gap, PA.

Arnold, Steven F., Diane M. Klotz, Bridgette M. Collins, Peter M. Vonier, Louis J. Guillette Jr., and John A. McLachlan (1996). "Synergistic Activation of Estrogen Receptor With Combinations of Environmental Chemicals," *Science*, Vol. 272, June 7.

Batte, Marvin T., D. Lynn Forster, and Fred J. Hitzhusen (1993). "Organic Agriculture in Ohio: An Economic Perspective," *Journal Production Agricultur*e, Vol. 6, No. 4.

Brattesani, Madeline, and Robert Elliott (1996). "The IPM Innovators Program," California Environmental Protection Agency, Department of Pesticide Regulation, Jan. 25.

Browner, Carol M., Administrator, U.S. Environmental Protection Agency; Richard Rominger, Deputy Secretary, U.S. Department of Agriculture; and David A. Kessler, Commissioner, Food and Drug Administration (1993). "Testimony before the Subcommittee on Department Operations and Nutrition Committee on Agriculture," U.S. House of Representatives, Sept. 22.

Buchman, Stephen L., and Gary P. Nabhan (1996). *The Forgotten Pollinators*. Washington, DC: Island Press/Shearwater Books.

Calkins, C. O., R. M. Faust, J. R. Coppedge, J. F. Brunner, L. D. Chandler, D. D. Hardee, and M. R. Bell (1996). *Areawide IPM as a Tool for the Future*, USDA, Agricultural Research Service, speech presented at the Third National IPM Workshop/Symposium, Feb.-March.

Cate, J.R., and M.K Hinkle (1994). *Integrated Pest Management: The Path of a Paradigm*. National Audubon Society, Alexandria, VA: Weadon Printing.

Coble, Harold D., and David A. Mortensen (1992). "The Threshold Concept and its Application to Weed Science," *Weed Technology*, Vol. 6, No. 1.

Dunn, Julie Anton (1995). *Organic Food and Fiber: An Analysis of 1994 Certified Production in the United States*, U.S. Department of Agriculture, Agricultural Marketing Service, Transportation and Marketing Division, Sept.

Edwards, C. Richard, and Richard E. Ford (1992). "Integrated Pest Management in the Corn/Soybean Agroecosystem," *Food, Crop Pests, and the Environment* (F. G. Zalom and W. E. Fry, ed.). The American Phytopathological Society, St. Paul, MN: APS Press.

Ferguson, Walter, and Jet Yee (1995). "A Logit Model of Cotton Producer Participation in Professional Scout Programs," *Journal of Sustainable Agriculture*, Vol. 5, No. 3.

Fernandez-Cornejo, Jorge (1996). "The Microeconomic Impact of IPM Technology," *Agricultural and Resource Economics Review*, Oct.

Ferro, David N. (1996). "Cultural Controls, Electronic IPM Textbook," (E. B. Radcliffe and W. D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Flint and Doane (1996). "Pheromones and Other Semiochemicals," Electronic IPM Textbook, (E. B. Radcliffe and W. D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (http://www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Glass, Edward H. (1992). "Constraints to the Implementation and Adoption of IPM," *Food, Crop Pests, and the Environment* (F. G. Zalom and W. E. Fry, ed.), American Phytopathological Society, St. Paul, MN: APS Press.

Gray, Michael E. (1995). "Status of CES-IPM Programs: Results of a National IPM Coordinators Survey," *American Entomologist*, Vol. 41, No. 3.

Hoban, Thomas J, and Patricia A. Kendall (1993). "Consumer Attitutes About Food Technology: Project Summary." U.S. Dept. Agr., Extension Service, North

Carolina State Univ. and Colorado State Univ., Project No. 91-EXCA-3-0155.

Hunter, Charles D. (1994). *Suppliers of Beneficial Organisms in North America*, PM 94-03, California Environmental Protection Agency, Department of Pesticide Regulation.

Jacobsen, Barry (1996). "USDA Integrated Pest Management Initiative," Electronic IPM Textbook, (E. B. Radcliffe and W. D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (http://www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Klassan, Waldemar, and Paul Schwartz, Jr. (19__). "ARS Research Program in Chemical Insect Control," *Agricultural Chemicals of the Future*, BARC Symposium 8 (James L. Hilton, ed.), Rowman & Allanheld, Totowa.

Kling, James (1996). "Could Transgenic Supercrops One Day Bred Superweeds?" *Science*, Vol. 274, Oct. 11.

Klonsky, Karen, and Peter Livingston (1994). "Alternative Systems Aim to Reduce Inputs, Maintain Profits," *California Agriculture*, Vol. 48, No. 5.

Knoblauch, Wayne A., Rebecca Brown, and Martin Braster (1990). "Organic Field Crop Production: A Review of the Economic Literature," A.E. Res. 90-10, Department of Agricultural Economics, Cornell University Agricultural. Experiment Station, Cornell University, Ithaca, NY, July.

Kogan, Marcos (1996). "Areawide Codling Moth Management," *IPM in the Western Region*, Sorrel Brown (ed.), NCR Educational Materials Project, Iowa State University.

Kogan, Marcos, ed. (1994). "Areawide Management of the Codling Moth: Implementation of a Comprehensive IPM Program for Pome Fruit Crops in the Western U.S.," Integrated Plant Protection Center, Oregon State University, July.

Landis, Douglas A., and David B. Orr (1996). "Biological Control: Approaches and Applications," Electronic IPM Textbook, (E.B. Radcliffe and W.D. Hutchison, ed.). University of Minnesota and the Consortium for International Crop Protection, Ted Radcliffe's Gopher State IPM Site (http://www.ent.agri.umn.edu/academics/classes/ipm/ipmsite.htm).

Lin, Biing-Hwan, Harold Taylor, Herman Delvo, and Len Bull (1995). "Factors Influencing Herbicide Use in Corn Production in the North Central Region," *Review of Agricultural Economics*, Vol. 17, No. 2.

Litovitz, T. L., B. F. Schmitz, and K. M. Bailey (1990). "1989 Annual Report of the American Association of Poison Control Centers National Data Collection System," *American Journal Emerging Medicine*, Vol. 8, pp. 394-442.

MacIntyre, Angus A. (1987). "Why Pesticides Received Extensive Use in America: A Political Economy of Agricultural Pest Management to 1970," *Natural Resources Journal*, Vol. 27, Summer.

Mullen, Jeffrey (1995). "Estimating Environmental and Human Health Benefits of Reducing Pesticide Use Through Integrated Pest Management Programs," M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, Aug.

Nash, Jennifer, and John Ehrenfeld (1996). "Code Green: Business Adopts Voluntary Environmental Standards," *Environment*, Vol. 38, No. 1.

National Academy of Sciences (1995). *Ecologically Based Pest Management: New Solutions for a New Century.* National Research Council, Board on Agriculture, Washington, DC: National Academy Press.

Natural Foods Merchandiser (1996). "Widening Market Carries Organic Sales to $2.8 Billion in 1995," *Natural Foods Merchandiser*, Vol. XVII, No. 6. New Hope Communications.

Niebling, Kenneth (1995). "Agricultural Biotechnology Companies Set Their Sights on Multi-Billion $$ Markets," *Genetic Engineering News*, July.

Ollinger, Michael, and Jorge Fernandez-Cornejo (1995). *Regulation, Innovation and Market Structure in the U.S. Pesticide Industry*, USDA, Economic Research Service, AER-719, June.

Orzalli, Rick, Bob Curtis, and Hasan Bolkan (1996). "Implementing IPM Programs, Keys to Success: Campbell Soup Company," speech presented at the Third national IPM Workshop/Symposium, Feb.-March.

Osteen, Craig (1987). "The Policy and Economic Issues of Pest Control and Energy Use," Zane R. Helsel (ed.), *Energy in World Agriculture*, Elsevier Press.

Osteen, Craig, and Philip Szmedra (1989). *Agricultural Pesticide Use Trends and Policy Issues*, USDA, Economic Research Service, AER-622, Sept.

Padgitt, Merritt (1996). "Cropping Practices Survey, 1990-1995 Summary: Pesticide Use and Application Practices," USDA, Economic Research Service, unpublished statistical summary, May 6.

Pease, William S., James Liebman, Dan Landy, and David Albright (1966). "Pesticide Use in California: Strategies for Reducing Environmental Health Impacts." California Policy Seminar, University of California, Berkeley, Center for Occupational and Environmental Health.

Pimentel, David, H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, and M. D'Amore (1992). "Environmental and Economic Costs of Pesticide Use," *BioScience*, Vol. 42, No. 10.

Poritz, Noah (1996). "Biological Control of Weeds: An Alternative," *Biological Control of Weeds 1996*, Bozeman, MT.

Public Law: 104-170, 104th Congress (1966). Food Quality Protection Act, EPA, Prevention, Pesticides and Toxic Substances, 7501W, Nov.

Rajotte, Edwin G., Richard F. Kazmierczak, Jr., George W. Norton, Michael T. Lambur, and William A. Allen (1987). *The National Evaluation of Extension's Integrated Pest Management (IPM) Programs*, Virginia Cooperative Extension Service Publication 491-010, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Ricker, Harold S. (1996). "The National Organic Program - Status and Issues," Third National IPM Symposium/Workshop: A Proceedings," USDA, Economic Research Service, forthcoming.

Ridgway, R. L., M. N. Inscoe, and K. W. Thorpe (1994). "Biologically Based Pest Controls: Markets, Industries, and Products," Special Report for OTA, Beltsville Agricultural Research Center, USDA, Agricultural Research Service, May 20.

Salquist, T. (1994). "Dawn of Genetic Engineering," *Farm Chemicals*, Sept.

Schwartz, P.H., and W. Klassen (1991). "Current Crop Losses to Pests Despite the Use of Pesticides and Other Controls," Unpublished manuscript.

U.S. Department of Agriculture (1994). *IPM The Annual Report: State Accomplishments 1993*, USDA, Cooperative Extension System.

U.S. Environmental Protection Agency (1997). "Questions & Answers: Potential of Chemicals to Affect the Endocrine System," *Prevention, Pesticides and Toxic Substances* (7506C), Jan. 30.

________________________________ , (1996a). "Exemption of Certain Pesticide Substances From Federal Insecticide, Fungicide, and Rodenticide Act Requirements," Federal Register, Vol. 61, No. 45.

________________________________ , (1996b). "Partnerships in Preventing Pollution: A Catalogue of the Agency's Partnership Programs," EPA 100-B-96-001, Office of the Administrator, Spring.

________________________________, (1995). "EPA Issues Conditional Approval for Full Commercial Use of Field Corn Plant Pesticide Targeting the European Corn Borer," EPA Press Release, Aug. 11.

________________________________, (1987). *Unfinished Business: A Comparative Assessment of Environmental Problems*. Vol. 1 Overview, Feb.

U.S. Congress, Office of Technology Assessment (1995). *Biologically Based Technologies for Pest Control*, OTA-ENV-636, Washington, DC: Government Printing Office.

Vandeman, Ann, Jorge Fernandez-Cornejo, Sharon Jans, and Biing-Hwan Lin (1994). *Adoption of Integrated Pest Management in U.S. Agriculture*, AIB-707, USDA, Economic Research Service, Sept.

Van Zee, Vicki (1992). "Partners with Nature: A Massachusetts Integrated Pest Management Recognition Program," *Fruit Notes*, Vol. 57, No. 4, Massachusetts Department of Food and Agriculture.

White, Janet (1994). "Farming in Transition: Editor's Note," *California Agriculture*, Vol. 48, No. 5.

Zalom, F. G., and W. E. Fry (1992a). *Food, Crop Pests, and the Environment*, American Phytopathological Society, St. Paul, MN: APS Press.

Zalom, F. G., and W. E. Fry (1992b). "Biologically Intensive IPM for Vegetable Crops," *Food, Crop Pests, and the Environment*, American Phytopathological Society, St. Paul, MN: APS Press.

Recent ERS Research on Pest Management Issues

Proceedings of the Third National IPM Symposium/Workshop: Broadening Support for 21st Century IPM, May 1997, Miscellaneous Publication Number 1542 (Sarah Lynch, Cathy Greene, and Carol Kramer-LeBlanc, editors). IPM program assessment was a major focus of the interdisciplinary IPM symposium/workshop held last winter in Washington DC. Several papers in this proceedings explore ways to incorporate the economic, environmental, and public health impacts of IPM programs into research and extension activities.

"Organically Grown Vegetables: U.S. Acreage and Markets Expand during the 1990's," April 1997, VGS-271, *Vegetables and Specialties: Situation and Outlook Report* (Catherine Greene and Linda Calvin). Organic farming systems, which focus on ecologically-sound production practices, have been gaining ground among U.S. vegetable growers during much of the 1990's. Organic vegetables are currently being grown and certified by State and private agencies on about 1 percent of U.S. vegetable acreage—ranging from 0.2 percent to over 10 percent in top vegetable States—and implementation of national standards is expected to facilitate the use of these systems.

Pest Management on Major Field Crops, AREI Updates, No. 1, February 1997 (Merritt Padgitt). This report breaks out the use of herbicides and insecticides on major field crops (corn, soybeans, winter wheat, cotton, and potatoes) in 1995 by the various tillage systems, crop rotations, plant densities, row sizes, and number of cultivations that were used in producing these crops.

"The Microeconomic Impact of IPM Adoption," *Agricultural and Resource Economics Review*, October 1996 (Jorge Fernandez-Cornejo). This report develops a methodology to calculate the impact of integrated pest management (IPM) on pesticide use, yields, and farm profits. While the methodology in this case study is applied to IPM adoption among fresh market tomato producers for insect and disease management, the method is of general applicability. It accounts for "self-selectivity" (IPM adopters may be better farm managers or differ systematically from nonadopters in some other way) and simultaneity—farmers' IPM adoption decisions and pesticide use may be simultaneous—and the pesticide demand and yield equations are theoretically consistent with a profit function. In this study, IPM was defined operationally as the use of scouting and thresholds for making insecticide and fungicide applications and the use of one or more additional IPM techniques for managing pests.

"The Diffusion of IPM Techniques by Vegetable Growers," *Journal of Sustainable Agriculture*, Vol. 7, No. 4 (Jorge Fernandez-Cornejo and Alan Kackmeister). This study examines the adoption/diffusion paths of various integrated pest management (IPM) techniques among vegetable growers in 15 states, as well as grower education, regional research levels, and other factors that influence adoption. The authors concluded that the IPM techniques examined would reach 75 percent adoption between 2008 and 2036, except for scouting, which attains the 75 percent level during the 1990's.

Organic Vegetable Growers Surveyed in 1994, AREI Updates, No. 4, May 1996 (Jorge Fernandez-Cornejo, Doris Newton, and Renata Penn). This statistical bulletin reports the first national level statistics on organic production practices in the U.S. vegetable industry. A sample of 303 organic vegetable growers, close to one-fifth of all certified organic vegetable growers, was obtained from the 1994 USDA Chemical Use Survey, and the report presents selected pest and nutrient management practices used by these growers, as well as socioeconomic statistics describing the growers.

"Factors Influencing Herbicide Use in Corn Production in the North Central Region," *Review of Agricultural Economics*, Vol. 17, No. 2, 1995, (Biing-Hwan Lin, Harold Taylor, Herman Delvo, and Leonard Bull). In this report, factors that influence herbicide use in corn production—including tillage practices, crop rotation, application method, and farm program participation—are analyzed using field-level data for 1990-1992 from the 10 major corn producing states. The authors found that herbicide use could be greatly reduced by switching from broadcast to band applications, and that switching from conventional to conservation tillage, without using the moldboard, plow sometimes increases herbicide use.

Adoption of Integrated Pest Management in U.S. Agriculture, AIB-707, September 1994 (Ann Vandeman, Jorge Fernandez-Cornejo, Sharon Jans, and Biing-Hwan Lin). This report summarized information on the extent of adoption of surveyed integrated pest management (IPM) techniques in the production of dozens of fruit and vegetable crops and several major field crops in the early 1990's. In this report, which was based on USDA survey data, farmers were considered to be using IPM if they scouted their crop acreage and based their decision to apply pesticides on whether pests had reached an economically damaging threshold. Using this definition, over half of the acreage of surveyed growers was being produced under IPM, with adoption rates and the additional pest management practices used, varying by crop and State.
(Contact to obtain reports: Catherine Greene, (202) 219-0466 [cgreene@econ.ag.gov])